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*GENETIC LOAD IN TRIBOLIUM**

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The paper of Morton, Crow, and Muller,[1] which presented a method designed to differentiate between mutational and balanced (segregational) loads, stimulated a great deal of research on the subject, and generated considerable controversy. Both the validity of the technique (see Crow[2] and Levene[3] for references), as well as the interpretation of the results in different species (Neel[4] summarizes the extensive human material; Malogolowkin-Cohen, Levene, Dobzhansky, and Solima Simmons[5] may be consulted for literature on Drosophila), have been questioned.

Much of the dispute on the utility of the method proposed by Morton, Crow, and Muller sprang from theoretical considerations of both mathematical and biological nature. But an even more important source of disagreement existed in the comparative dearth of extensive and accurate data. Some of the information on man suffers from unreliability, partly as a result of intrinsic inaccuracies of field material and partly because of scant numbers.[4] Inferences from studies on domestic animals[6] are complicated by their previous history of inbreeding. Even the Drosophila material reported upon in the early investigations was, relatively speaking, limited.

It was hence thought that species of the flour beetle, Tribolium, which possess many advantages as experimental material for population genetics studies (Sokoloff and Shrode[7]), could be profitably utilized in a diversified mass test of the Morton, Crow, and Muller model.

Essentially, the experimental procedure in such a test involves comparison of survival rates from egg to larva and from larva to adult of the offspring from matings between full sibs, half sibs, and unrelated parents. Experiments were undertaken on two species, *T. castaneum* (hereafter designated as CS) and *T. confusum* (to be referred to as CF), in each of two environments differing in relative humidity. The different kinds of strains investigated included, for each species, two natural populations, a stock derived from a cross between them, a synthetic laboratory population constituted from a number of wild strains, a heterozygous population reconstituted from a four-way cross of inbred lines, and a highly inbred line.

Materials and Methods.—The natural populations of CS were derived from samples in animal feed storage rooms of the Department of Zoology, University of California, Davis, and at a flour mill in Oakland, California, respectively. Similarly, the CF strains were obtained from storage bins containing mash in the Poultry Department, University of California, Berkeley, and from the same flour mill in Oakland as the CS population. Over 100 adults of these CS and CF strains were introduced into fresh medium and transferred three or four times to new culture bottles at 3-day intervals. Each strain was thus initiated from numerous eggs laid by the captured adults.

The two synthetic populations were formed some 3 years before the experiments were started by crossing a number of laboratory lines of various geographical origins. Also, a series of inbred lines maintained by brother × sister mating was produced from the synthetic population of each species.[8] The CS synthetic strain, and the inbred lines derived from it, are marked with sooty, an autosomal body color gene. The heterozygous populations studied were established from a four-way cross of the inbreds after some 30 generations of inbreeding. Finally, the inbred lines used were chosen, on basis of high productivity, from the surviving lines after 32 generations of brother × sister mating.

From each of the noninbred strains studied, 10 males were selected at random, and each male was placed with 3 virgin females in a small vial containing standard medium (19 parts by weight of whole wheat flour and 1 part of dried brewer's yeast). A crossbred population of each species was initiated by mating each of 10 University of California males to 3 Oakland females.

After 3 days the males were isolated, and the females transferred individually to vials marked 1*a*, *b*, *c*, 2*a*, *b*, *c*, . . ., 10*a*, *b*, *c*. After a week the females were transferred to another set of vials. If no viable eggs had been produced, the females were remated with the same male. The procedure for the inbred strains was the same, although here the initial matings were brother × sister.

When pupae appeared, they were isolated according to sex and allowed to metamorphose. Adults, 5 or 6 days old, were mated as follows: (*a*) full-sib matings—one male from each of the *a* (1–10) vials was mated with 20 females from the same vial; (*b*) half-sib matings—one male from each of the *a* (1–10) vials was mated with 20 females from the *b* (1–10) vials; (*c*) "random" mating—to ensure that no brother × sister matings occurred, males from vials *c* (1–5) were mated with females from the *c* (6–10) vials and vice versa, for a total of 100 single-pair matings.

After a week the females were isolated in individual 1-dram vials half-filled with standard medium. Half of the vials were placed in an incubator maintained at 29°C and 70% relative humidity, and the other half in another incubator kept at 29°C and approximately 40% relative humidity.

Three days later, 20 eggs were chosen at random from each vial, placed in 1-dram vials containing approximately $1^1/_2$ gm of standard medium, and returned to their respective incubators. The female was considered unfertilized if a small number of eggs were found (less than 10) or if the eggs appeared abnormal (collapsed, discolored, or shrivelled). She was then remated with her original partner. Larvae were recorded 18 days later. Adults were counted and discarded 27 days after the larval count.

Because of apparent nonlinearity in some of the strains, the series involving the CS strain reconstituted from four inbred strains (cross *A* in Table 1) was repeated with some modifications about 18 months later, when the lines had been inbred for 42 generations, as a test case. By then one of the inbred lines was extinct and a related subline was substituted in the four-way cross (*B* in Table 1). In addition a similar series (cross *C*) was initiated, using single-pair full- and half-sib matings instead of mating one male with 20 females.

In order to distribute the work load, the CS matings were made 3 weeks before the parallel experiments with CF.

During the process of counting the adults it was noted that some beetles were still in the pupal stage. For computation purposes it has been assumed that they would have become adults. It was also found that in some vials there were a number of tiny larvae 45 days after the experiment was begun. These larvae (never exceeding 1% in any of the strains) were assumed to die before becoming imagoes.

Methods of Analysis.—Survival values in each of the 20 vials sired by one male are correlated. There is a similar correlation within groups of 20 single-pair matings,

since some of the males are brothers or half brothers to each other and some of the females are similarly sisters or half sisters. Accordingly, the basic data used for the analysis were the sums of 10 replicates, which provided 10 independent observations for each strain-humidity combination. From these observations the proportion of eggs becoming larvae, the proportion of eggs becoming adults, and the proportion of larvae becoming adults were calculated.

The data were analyzed on the IBM 1620 computer at the Survey Research Center of the University of California, Berkeley. Estimates of A, B, and B/A of Morton, Crow, and Muller[1] were obtained by weighted regression analysis, in the manner of Malogolowkin-Cohen, Levene, Dobzhansky, and Solima Simmons.[5] The variances in the two environments were similar and therefore were combined, providing 18 degrees of freedom for estimating parameters separately at the two humidities.

A serious objection to the procedure is that the ratio of the estimates of B to A is a biased estimate of the true B/A. It can be shown that the bias is of the order $1/N$, where N is the effective number of observations (somewhere between 6000 eggs and 30 viability values), while the expression

$$B/A - (B/A^2)\mathrm{Var}A + (1/A^2)\mathrm{Cov}AB \qquad (1)$$

has a bias only of the order $1/N^2$, and hence is more satisfactory. In these data the bias is more serious than in the data of Malogolowkin-Cohen *et al.*,[5] since each strain-humidity combination is based only on 6000 eggs, and therefore the estimates have comparatively large variances.

An appealing way of reducing the bias to the order of $1/N^2$ is provided by the unpublished so-called "jackknife" method of Tukey (see Miller[9]). Using it, the 30 basic observations for each strain-humidity combination were combined into 10 groups of three, every group using corresponding cultures for each of the three levels of inbreeding. Ten estimates of B/A were then obtained by weighted regression on nine observations consisting of all but the ith group. These are denoted by $R_i^{(9)}$, $i = 1, \ldots 10$. If $R^{(10)}$ is the estimate of B/A obtained from all 10 groups, then $R_i = 10\ R^{(10)} - 9\ \mathrm{R}_i^{(9)}$ are approximately independent estimates of B/A, and their mean, $\bar{R}$, and standard deviation may be calculated. The estimate $\bar{R}$ will have the required smaller bias, and Student's distribution with nine degrees of freedom may then be used to obtain approximate confidence intervals for $\bar{R}$. The same procedure was used to obtain unbiased estimates and approximate empirical standard deviations for A and B separately. It should be pointed out that because of removal of the bias, the estimate of B/A is not equal to the ratio of the separate estimates of B and A.

The "jackknife" method and the estimate corrected by formula (1) differed on the average by less than 1 per cent, whereas the uncorrected estimates of B/A were found to have an upward bias averaging 3.5 per cent. On the other hand, biases in A and B were negligible. Finally, it was gratifying to find that the standard error obtained by the two methods were in reasonably good agreement. Since the "jackknife" procedure did reduce the bias, further analysis was based on its use. Values of A, the expressed load; of B, the concealed load; and of B/A are given in Tables 1 and 2. The values for larva to adult mortality are very small, thereby producing erratic B and B/A estimates. As a result, the egg to larva and

TABLE 1

ESTIMATES OF A, B, AND B/A FOR *Tribolium castaneum*

Population	Period	Humidity 70%			Humidity 40%		
		A	B	B/A	A	B	B/A
U. C. wild	Egg-larva	0.152 ± 0.031	0.501 ± 0.235	3.07 ± 1.92	0.182 ± 0.022	0.548 ± 0.246	2.94 ± 1.43
	Egg-adult	0.180 ± 0.033	0.619 ± 0.286	3.20 ± 1.99	0.217 ± 0.022	0.610 ± 0.275	2.76 ± 1.31
	Larva-adult	0.028 ± 0.007	0.108 ± 0.104	3.00 ± 4.65	0.036 ± 0.004	0.072 ± 0.038	1.95 ± 1.17
Oakland wild	Egg-larva	0.203 ± 0.029	0.613 ± 0.242	2.84 ± 1.57	0.193 ± 0.030	0.573 ± 0.261	2.77 ± 1.77
	Egg-adult	0.238 ± 0.033	0.779 ± 0.267	3.10 ± 1.57	0.229 ± 0.031	0.830 ± 0.265	3.47 ± 1.53
	Larva-adult	0.033 ± 0.008	0.116 ± 0.067	2.96 ± 2.79	0.036 ± 0.013	0.222 ± 0.073	4.67 ± 4.56
U. C. × Oakland	Egg-larva	0.193 ± 0.035	1.183 ± 0.323	5.80 ± 2.35	0.201 ± 0.040	1.236 ± 0.242	5.84 ± 1.89
	Egg-adult	0.223 ± 0.037	1.380 ± 0.350	5.87 ± 2.32	0.244 ± 0.037	1.570 ± 0.214	6.27 ± 1.44
	Larva-adult	0.029 ± 0.011	0.171 ± 0.106	3.68 ± 6.59	0.038 ± 0.008	0.312 ± 0.100	7.74 ± 3.56
Synthetic	Egg-larva	0.198 ± 0.016	0.986 ± 0.266	4.93 ± 1.51	0.201 ± 0.032	0.921 ± 0.254	4.41 ± 1.61
	Egg-adult	0.234 ± 0.021	1.090 ± 0.264	4.63 ± 1.18	0.228 ± 0.038	1.059 ± 0.262	4.44 ± 1.61
	Larva-adult	0.035 ± 0.010	0.095 ± 0.056	2.24 ± 2.14	0.029 ± 0.009	0.104 ± 0.089	2.15 ± 5.10
4-Way inbred lines cross A	Egg-larva	0.244 ± 0.057	0.827 ± 0.392	2.75 ± 2.84	0.341 ± 0.051	0.276 ± 0.407	0.62 ± 1.35
	Egg-adult	0.286 ± 0.057	0.868 ± 0.396	2.61 ± 2.27	0.398 ± 0.050	0.290 ± 0.430	0.60 ± 1.21
	Larva-adult	0.037 ± 0.009	0.043 ± 0.058	0.80 ± 1.98	0.050 ± 0.009	0.077 ± 0.085	1.31 ± 1.92
4-Way inbred lines cross B	Egg-larva	0.701 ± 0.064	0.247 ± 0.424	0.33 ± 0.62	0.768 ± 0.081	−0.022 ± 0.425	−0.05 ± 0.55
	Egg-adult	0.791 ± 0.063	0.192 ± 0.428	0.23 ± 0.55	0.815 ± 0.088	−0.060 ± 0.425	−0.10 ± 0.52
	Larva-adult	0.085 ± 0.024	−0.043 ± 0.136	−0.90 ± 1.62	0.051 ± 0.020	−0.090 ± 0.106	−2.42 ± 1.82
4-Way inbred lines cross C	Egg-larva	0.569 ± 0.035	0.193 ± 0.202	0.32 ± 0.37	0.671 ± 0.047	0.237 ± 0.320	0.32 ± 0.51
	Egg-adult	0.632 ± 0.029	0.228 ± 0.203	0.35 ± 0.33	0.718 ± 0.048	0.240 ± 0.322	0.31 ± 0.48
	Larva-adult	0.062 ± 0.014	0.042 ± 0.056	0.45 ± 1.06	0.042 ± 0.011	0.028 ± 0.072	0.23 ± 1.84
Inbred line 5	Egg-larva	0.623 ± 0.022	0.739 ± 0.254	1.17 ± 0.44	1.057 ± 0.049	1.684 ± 0.341	1.58 ± 0.36
	Egg-adult	0.646 ± 0.024	0.757 ± 0.267	1.16 ± 0.45	1.081 ± 0.051	1.870 ± 0.337	1.72 ± 0.34
	Larva-adult	0.024 ± 0.006	0.013 ± 0.031	0.53 ± 1.37	0.021 ± 0.004	0.159 ± 0.043	7.28 ± 2.82

TABLE 2

ESTIMATES OF A, B, AND B/A FOR *Tribolium confusum*

Population	Period	Humidity 70%			Humidity 40%		
		A	B	B/A	A	B	B/A
U. C. wild	Egg-larva	0.274 ± 0.021	0.222 ± 0.189	0.76 ± 0.75	0.302 ± 0.033	0.622 ± 0.226	1.98 ± 0.93
	Egg-adult	0.316 ± 0.018	0.234 ± 0.230	0.71 ± 0.77	0.335 ± 0.032	0.518 ± 0.207	1.49 ± 0.74
	Larva-adult	0.041 ± 0.009	0.095 ± 0.075	1.94 ± 2.28	0.028 ± 0.005	0.054 ± 0.040	1.73 ± 1.65
Oakland wild	Egg-larva	0.299 ± 0.052	0.499 ± 0.363	1.44 ± 1.55	0.188 ± 0.029	0.925 ± 0.218	4.69 ± 1.75
	Egg-adult	0.319 ± 0.052	0.801 ± 0.428	2.24 ± 1.79	0.216 ± 0.033	1.151 ± 0.296	5.09 ± 1.94
	Larva-adult	0.012 ± 0.004	0.344 ± 0.138	23.18 ± 18.05	0.020 ± 0.007	0.273 ± 0.102	10.41 ± 9.63
U. C. × Oakland	Egg-larva	0.214 ± 0.026	0.819 ± 0.234	3.64 ± 1.61	0.222 ± 0.017	0.576 ± 0.266	2.53 ± 1.32
	Egg-adult	0.230 ± 0.028	0.880 ± 0.257	3.65 ± 1.63	0.241 ± 0.019	0.722 ± 0.282	2.94 ± 1.30
	Larva-adult	0.016 ± 0.004	0.049 ± 0.040	2.49 ± 3.29	0.018 ± 0.003	0.154 ± 0.029	8.25 ± 2.21
Synthetic	Egg-larva	0.221 ± 0.027	0.182 ± 0.293	0.68 ± 1.42	0.166 ± 0.017	0.619 ± 0.202	3.63 ± 1.45
	Egg-adult	0.246 ± 0.028	0.200 ± 0.321	0.68 ± 1.39	0.183 ± 0.017	0.711 ± 0.230	3.80 ± 1.46
	Larva-adult	0.024 ± 0.004	0.027 ± 0.055	0.86 ± 2.33	0.016 ± 0.004	0.061 ± 0.028	3.60 ± 2.31
4-Way inbred lines cross	Egg-larva	0.274 ± 0.025	−0.287 ± 0.140	−1.06 ± 0.48	0.276 ± 0.027	−0.250 ± 0.096	−0.93 ± 0.28
	Egg-adult	0.287 ± 0.025	−0.322 ± 0.136	−1.13 ± 0.44	0.282 ± 0.032	−0.237 ± 0.119	−0.88 ± 0.35
	Larva-adult	0.014 ± 0.007	−0.041 ± 0.033	−3.46 ± 1.20	0.007 ± 0.004	0.009 ± 0.019	−1.88 ± 5.44
Inbred line 1b	Egg-larva	0.481 ± 0.052	0.283 ± 0.448	0.52 ± 1.01	0.458 ± 0.027	0.208 ± 0.409	0.44 ± 0.92
	Egg-adult	0.521 ± 0.049	0.250 ± 0.455	0.43 ± 0.93	0.480 ± 0.028	0.252 ± 0.430	0.50 ± 0.92
	Larva-adult	0.037 ± 0.006	−0.018 ± 0.024	−0.50 ± 0.63	0.022 ± 0.004	0.048 ± 0.025	2.04 ± 1.19

egg to adult mortality are similar. Since the egg to adult mortality is a better measure of the total load, all further discussion will refer to it.

Analyses of variance of the original data showed that there was little difference in mean viability at the two humidities, and it seemed justifiable to combine data from them. Because of the difference in weighting at the two humidities, the estimated parameters for the combined data were not always intermediate, but whenever such discrepancies occurred, they were very slight. Since in combining the data for the two humidities the viabilities were averaged, the estimated variance is based on nine degrees of freedom. Figure 1 shows the combined estimates for A, B, and B/A, as well as the lower and upper 95 per cent confidence limits.

Results and Discussion.—In general, the results are in agreement with those previously reported for Drosophila. For the five outbred lines in each species, the expressed load, given by A, varies between 0.20 and 0.39 with mean values of 0.28 and 0.27 for CS and CF, respectively. The inbred CS gives A = 0.84, and the inbred CF 0.50, or a much larger expressed load, as would be expected for a less viable inbred line. An unexplained result is the high A value for each of the two repeats of the four-way hybrid in CS. To be sure, one of the four strains involved is not the same and environmental conditions may have somehow changed, but the difference is uncomfortably large.

The concealed loads, as estimated by B, vary from −0.26 to 1.06 for the outbred strains, with means of 0.75 for CS and 0.44 for CF. The

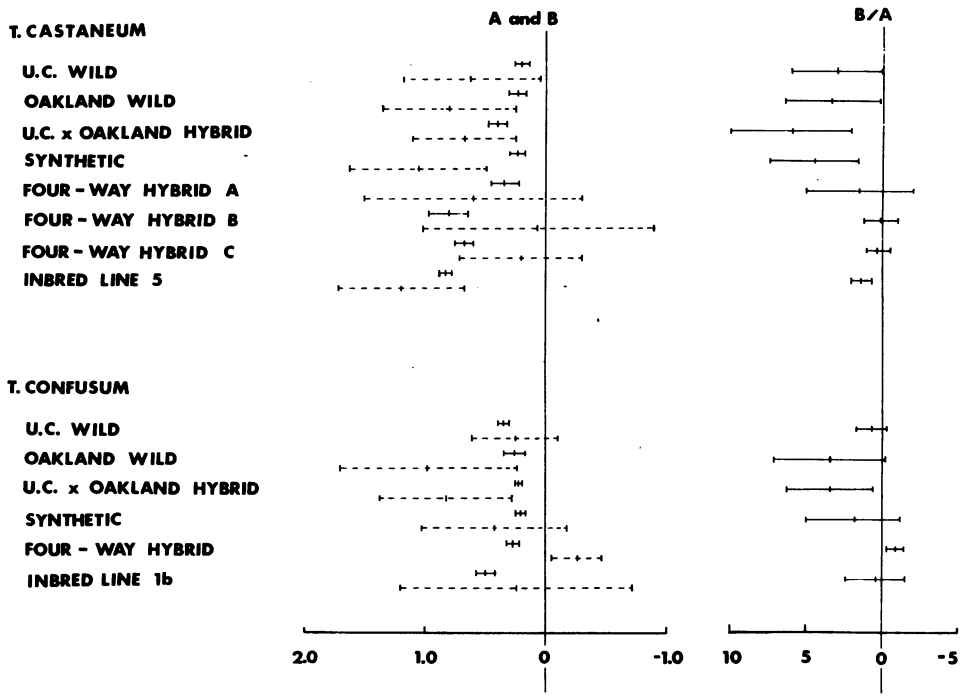

FIG. 1.—Combined estimates for A, B, and B/A and their lower and upper 95% confidence limits for various populations of *Tribolium castaneum* and *T. confusum*. The scale runs from right to left. (On the left A is given by solid lines and B by dashed lines.)

B values for the two repeats of the four-way cross in CS are low, suggesting that most of the load in these experiments was expressed rather than concealed, further adding perplexity. In the CF inbred line B was low, but with a large standard error, so that quite high values are possible, as are negative values. Another surprising result is the value of B for the inbred CS strain. Even the lower 95 per cent confidence limit is large, suggesting that in spite of a history of 32 generations of brother-sister mating, the amount of concealed deleterious recessives carried is still quite large. This could be due to interline selection for fitness between offspring of different sib matings keeping this line heterozygous for heterotic genes or gene combinations that are deleterious when homozygous.

The B/A ratios, as always, are more variable, varying from 0 to 6 in CS and from -0.9 to 3.5 in CF, with means of 3.7 and 1.7, respectively, for the outbred strains. The values for the inbred strains and the two repeats are all well under 2. In general, the values of B/A are considerably less than those for Drosophila; however, they vary considerably from strain to strain, indicating the danger of drawing conclusions for a species from studies of one or a few populations. If the B/A ratio gave a reliable estimate of the relative size of the mutational and balanced loads, which the present authors doubt, these data would give little or no evidence for a large mutational component.

Since there are apparent differences between different strains, further statistical tests were made. First, tests of heterogeneity between strains, based on the variances found by the "jackknife" method, were carried out. Heterogeneity between

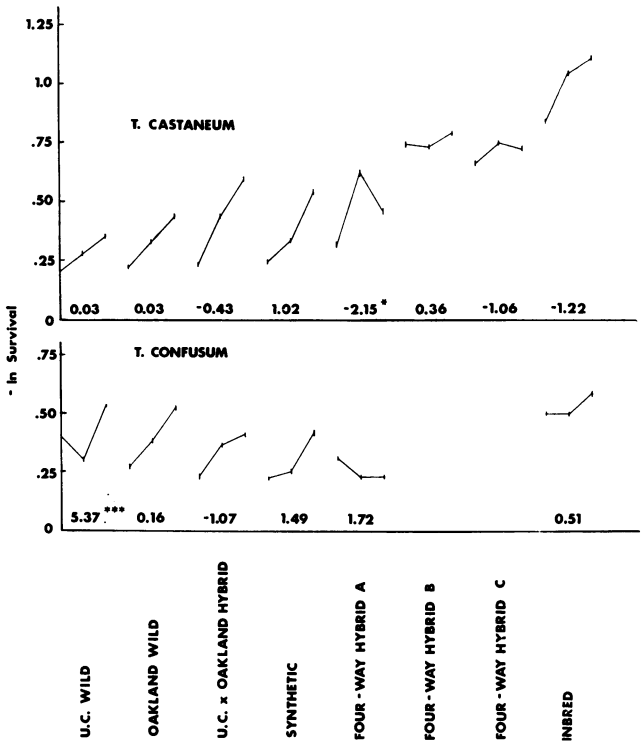

FIG. 2.—Proporton of eggs surviving to adults (expressed by $y = -\log_e$) for $F = 0$, $1/8$, and $1/4$ in various populations of *Tribolium castaneum* and *T. confusum*. The numbers below each curve are t values for nonlinearity (* = significant at the 5% level; *** = significant at the 0.1% level).

the A, and B, and the B/A values for 70 per cent, 40 per cent, and both humidities combined for the five outbred strains were significant for CF at the 0.1 per cent level, except for A at 70 per cent humidity which was significant at the 5 per cent level. On the other hand, for CS only the values at 40 per cent, and B for the combined data were significant, and then only at the 5 per cent level. Thus, averaging the results from all outbred strains would seem to be more legitimate for CS than for CF. However, in neither case is the average a really meaningful estimate of the situation for the species as a whole, since in each case two of the five strains are wild populations, and the others are rather special. For the same reason, a comparison between the two species is not very meaningful; nevertheless, the differences in the means for the outbred strains of the two species were tested, both using the sum of their individual variances as error, and by a simple two-sample t test. In no case was the difference significant by either method. While the CS inbred strain has a significantly greater A value, and a just significantly greater B value, than the CF inbred, this difference should probably be attributed to the difference in the inbred strains used, rather than to any real species difference.

The data on Drosophila[5] indicate a lack of linearity in inbreeding effects, with a greater than proportional load, as measured by $y = -\log_e$ (proportion surviving) at higher inbreeding values. Such a depature, if real, may be attributed to epistatic interactions (synergism). In Figure 2 the values of y are given for egg to adult

survival for the combined humidities; and for the three values of the inbreeding coefficient, F, of 0, $1/8$, and $1/4$. It will be noted that some of the graphs are practically linear, others are concave upward, indicating positive synergism, with the combination of several deleterious genes being worse than predicted, while others are convex upward, indicating negative synergism or compensation by deleterious genes acting together. Nonlinearity was tested using $8(y_1 + y_3 - 2y_2)$, where y_1, y_2, y_3 correspond to $F = 0, 1/8, 1/4$, which is the difference between the slope of the second line segment and the first. Its variance is 64 [Var (y_1) + Var (y_3) + 4 Var (y_2)]. The value of t (the difference divided by its standard deviation) is shown under each graph. It may be seen that the four-way hybrid A for CS shows significant negative synergism at the 5 per cent level, and the University of California wild strain of CF shows significant positive synergism at the 0.1 per cent level, with none of the other values being statistically significant. The individual values can be combined for testing in two different ways to answer two different questions. First, we may add all the values of $8(y_1 + y_3 - 2y_2)$ algebraically, and test the sum against the square root of the sum of the variances. This tests whether there is significant synergism in a consistent direction. The mean difference in the two slopes for all strains tested is 0.86 ± 0.33 for CF, giving significant positive synergism, while for CS the difference is -0.58 ± 0.43, which is nonsignificantly negative, with an upper 95 per cent confidence limit of $+0.27$. Hence there still might be some positive synergism here also.

The second way to combine the data is to square the individual t values and add them. The sum has approximately a Chi-square distribution with as many degrees of freedom as there are t values. This tests for an over-all tendency to nonlinearity, but not necessarily in a consistent direction. For CF, $\chi^2 = 35.4$ with 6 degrees of freedom, which is significant at the 0.1 per cent level, while for CS, $\chi^2 = 8.6$ with 8 degrees of freedom, which is not significant. Thus there is good evidence of epistatic effects in one species, but not in the other, emphasizing the difficulty of drawing general conclusions from the kind of data and the methods of analysis used.

Conclusions.—(1) Estimates of A, B, and B/A in Tribolium appear to be of the same general order of magnitude as in Drosophila. (2) There are, however, some differences in these parameters both between the two species studied, and within species between inbred and noninbred populations. Furthermore, different noninbred populations of *T. confusum* also show heterogeneity in the amounts of genetic load. (3) The relatively low magnitudes of B to A ratios, and the existence of unexplainable differences between the various populations make the Morton, Crow, and Muller method not a particularly useful one for discriminating between mutational and balanced loads. (4) Evidence for synergism of gene action at the level of inbreeding (half-sib and full-sib mating) studied was obtained for *T. confusum.*

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THE GENETICS OF A COMMON INDIAN DIGITAL ABNORMALITY

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While examining Orissan males for color vision, Ray noticed three unrelated men with short fourth toes among 2500, and showed that the condition was an irregular autosomal dominant. Since then, he has searched for the condition in this and other states, and has seen 118 cases. Besides these, 51 living and 34 dead short-toed members of the pedigrees have been reported. Most of the dead had died young and recently. Only 6 were two generations older than the propositi. The grand total affected is thus 206. Ray is responsible for collecting the pedigrees, and Haldane for their analysis. The condition is not rare. Ray has collected pedigrees of some other digital abnormalities, the commonest being dominant polydactylism. But short fourth toes are much more frequent than all the rest combined.

A similar and similarly inherited abnormality has been reported in Yucátan (M. Steggerda, 1942) and in Japan (S. Ogawa, 1953; S. Katsura and S. Hayakawa, 1938; and others) and a similar abnormality, with no data on inheritance, in the Congo. But it is very rare in people of European descent. R. R. Gates (1946) cited 7 European and North American pedigrees in which there was irregular dominant inheritance of short metacarpals, in a few of whose members a fourth toe was short, but nothing resembling our pedigrees in which the shortening of the metatarsal is only associated with other abnormalities in 8 per cent of cases. We publish a brief account of our findings here, because we believe them to throw new light on the nature of penetrance and expressivity, but mainly in the hope of stimulating anthropologists and geneticists to make a world-wide search for this condition. A full account will appear elsewhere (Ray, in preparation).

The condition, which is present at birth, is due to shortening of the fourth metatarsus. In 130 cases it was present on both feet, in 41 on the right foot only, and in 35 on the left only; 104 men and 102 women were affected. Other associated anomalies are not rare. Among 117 persons with short toes seen by Ray the following were found:

3 with short terminal phalanx of thumb, 2 bilateral, 1 unilateral

3 with unusually long index fingers on both hands